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Powder Coating as an Environmentally Acceptable Alternate to the System of MIL-P-53022 and MIL-PRF-22750

by Jeffrey L. Duncan

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Jeffrey L. Duncan
Weapons and Materials Research Directorate, ARL

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ATTN: Engineering Dept., Code 882 (Mr. Steve Allen)
814 Radford Blvd., Ste. 20325
Albany, GA 31704-0325

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14. ABSTRACT
Powder coatings offer potential performance and environmental benefits over conventional, solvent-based protective coatings. At the request of the Albany Marine Corps Logistics Base (MCLB), three powder coatings were evaluated as performance-based alternatives to the military specification coatings normally used on combat vehicles. Specimen panels, to which the powder coatings had been applied, were subjected to a selection of performance tests from MIL-P-53022, an epoxy primer specification, and from MIL-PRF-22750, an epoxy topcoat specification. These products are part of the U.S. Army's Chemical Agent Resistant Coating (CARC) system and are applied to all Army and Marine Corps tactical equipment. These substrates, 1020 steel with zinc phosphate pretreatment, bare aluminum, and aluminum with chromate conversion coating, were submitted, representing the materials from which vehicles are constructed. Coupled with the three powder coatings, that led to nine possible combinations of substrate and powder coating. With the exception of one minor problem, probably associated with substrate pretreatment rather than coating performance, all three powder coatings performed well, and the U.S. Army Research Laboratory believes they are acceptable for use at Albany MCLB as alternatives to the CARC specifications normally used.

15. SUBJECT TERMS
CARC, powder coating, Albany MCLB, experimental products program, EPP

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1. Background

In late 2000, Albany Marine Corps Logistics Base (MCLB) personnel contacted the Coatings Technology Team, Weapons and Materials Research Directorate, U.S. Army Research Laboratory (ARL) about a test program designed to approve the use of epoxy powder coatings as replacements for the standard chemical agent resistant coating (CARC) system used on tactical equipment, because ARL is the CARC Commodity Manager and the CARC approving authority for the Department of Defense. The powder coatings were to be used on a variety of equipment to replace the military specification MIL-P-53022 (*1*) epoxy primer and MIL-PRF-22750 (*2*) epoxy topcoat as applied to bare and pretreated aluminum and zinc phosphate pretreated steel. Normally, substitutions are for cases where those specifications do not meet volatile organic compounds (VOC) regulations in force or where new technology will provide more general benefits in the future or a more environmentally acceptable process for the user. Although these specification coatings are available in low-VOC formulations, the environmental benefits (zero VOC) and performance enhancements of powder coatings are well documented. The proposed test program and approval process fell under the auspices of ARL's Experimental Products Program (EPP), which is set up to evaluate performance alternatives to military specification finishing systems. After discussions to set the number and type of panels required, panels were submitted for three powder coatings on three different substrates.

2. Objective

The test program was designed to evaluate epoxy powder coatings as performance-based alternatives to the system of epoxy primer MIL-P-53022 and epoxy topcoat MIL-PRF-22750 on the substrates noted in section 1. As part of a military tactical system, the parts must have CARC as the finishing system, and for interior components this typically includes a requirement for the previously mentioned specifications. For exterior use, the powder would replace only the primer. The powder coating needed to perform as well as or better than the system it was to replace.

3. Approach

A set of laboratory tests was assembled to evaluate the performance of the epoxy powders as a primer or as a combination of the primer and epoxy topcoat CARC system. While the corrosion resistance test requirement for salt fog exposure in MIL-P-53022 is 336 hr, the standard used in

the EPP is 1000 hr, the same as for MIL-P-53084 (*3*), a lead and chromate free electrodeposition epoxy primer developed by the Coatings Technology Team. That material and its thermal curing process provide a much more appropriate performance standard for the powder coating process under consideration in this case. The supplied test panels represented the nine possible substrate/pretreatment/powder coating combinations envisioned by Albany MCLB and included the three substrates in combination with three powder coatings from the Sherwin-Williams Co. (Sherwin-Williams) as noted in Table 1. The white color is typical of epoxy primers in the CARC system, and the green and black colors are commonly used on interior surfaces of tactical equipment.

Table 1. Coatings and substrates.

Powder Coatings	Substrates
Sherwin-Williams EWS8-9004 white no. 17925	1020 steel with zinc phosphate pretreatment
Sherwin-Williams EGS2-9007 green no. 24533	Bare aluminum
Sherwin-Williams EBS8-9003 black no. 17038	Aluminum with chromate conversion coating

The tests normally performed in a powder coating EPP study such as this one are extracted from the primer and topcoat specifications as appropriate. They are selected as laboratory simulations of conditions that the tactical equipment is anticipated to encounter in the field, such as exposure to rain, gasoline, acid rain, oil, and hydraulic fluid. However, the ultimate (and military unique) tests are the chemical agent resistance and resistance of the coating to Decontaminating Solution No. 2 (DS2). Tests run in this program and their corresponding performance requirements are summarized in Table 2.

The topcoating test was modified slightly from that specified in no. 12 in Table 2, in that the panels were topcoated with MIL-C-53039 (*4*) and MIL-DTL-64159 (*5*), Type II. After curing, they were tested by crosshatch adhesion (American Society for Testing and Materials [ASTM] Standard D 3359 (*6*), Method B) and by wet tape adhesion after immersion for 24 hr in deionized water (FED-STD-141 (*7*), Method 6301). Due to the thickness of the supplied test panels, the mandrel flexibility test could not be performed, so the conical mandrel test in accordance with ASTM D 522 (*8*), Method A was used instead to evaluate adhesion of the powder coatings to the substrates.

Prior to any testing, the dry film thickness of the powder coatings was measured. The six steel panels provided for the salt fog test were used, and eight measurements were made on each, following the pattern on Figure 1 and making a total of 48 test points for each color. The electronic film thickness gauge calculated the film thickness as follows: for the white no. 17925, the low reading was 2.05 mil, the high reading was 3.41 mil, and the average was 2.52 ± 0.25 mil; for the green no. 24533, the low reading was 1.85 mil, the high reading was 3.20 mil, and the average was 2.54 ± 0.29 mil; and for the black no. 17038, the low reading was 1.91 mil, the high reading was 3.20 mil, and the average was 2.44 ± 0.29 mil.

Table 2. Summary of tests and corresponding performance requirements.

Test No.	Test	Reference	Procedure	Requirement
1	Chemical agent resistance	MIL-C-46168 (*9*), para 4.3.25	expose 5-cm^2 area for 1/2 hr	≤40 μg of nerve agent GD and 180 μg of mustard agent HD desorbed
2	Water resistance	MIL-P-53022, para 4.14	immerse in water at 23 ± 1 °C (77 ± 1 °F) for 168 hr	initial defects, indistinguishable after 2 hr from unexposed film
3	Hydrocarbon resistance	MIL-P-53022, para 4.15	immerse in hydrocarbon fluid at 23 ± 1 °C (77 ± 1 °F) for 168 hr	minor initial defects, indistinguishable after 24 hr from unexposed film
4	Lube oil resistance	MIL-PRF-22750, para 4.6.3	immerse in lube oil at 121 ± 3 °C (250 ± 5 °F) for 168 hr	no defects after 4-hr recovery
5	Hydraulic fluid resistance	MIL-PRF-22750, para 4.6.3	immerse in hydraulic fluid at 65.5 ± 3 °C (150 ± 5 °F) for 168 hr	no defects after 4-hr recovery
6	DS2 resistance	MIL-C-46168, para 4.3.24	expose to DS2 for 1/2 hr	no blistering, wrinkling, or film softening, ΔE_{NBS} ≤2.5 units
7	Acid resistance	MIL-C-46168, para 4.3.21	expose to 10% acetic acid for 1 hr	no blistering and no change from the original color
8	Color	FED-STD-595 (*10*)	compare to standard color chip	visual match
9	Gloss (60° and 85°)	ASTM D 523 (*11*)	instrumental measurement	color dependent
10	Crosshatch adhesion	ASTM D 3359	see ASTM 3359	rating 4B or better
11	Flexibility	MIL-P-53022, para 4.13	1/4-in mandrel bend	no cracking or flaking
12	Intercoat adhesion	MIL-P-53022, para 4.17	apply CARC topcoat	no attack on primer, difficult to remove
13	Salt fog resistance	ASTM B 117 (*12*)	1000-hr exposure to ASTM B 117 method	no more than 5 scattered blisters ≤1 mm in diameter

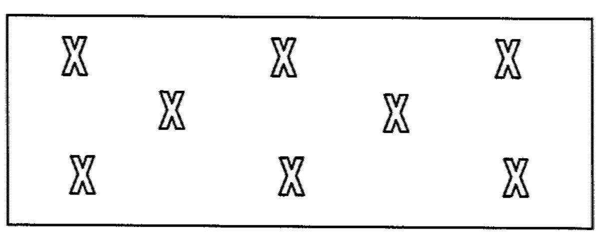

Figure 1. Test panel locations where film thickness was measured.

While most measurements fell within a typical range of 2–3.5 mil, several had either thinner or thicker films. Where film thickness was an important factor in a test (i.e., flexibility), every effort was made to use a panel with the typical (assumed to be production) film thickness. Where film thickness was not as important (e.g., DS2 or acid resistance), the most appropriate panel was selected.

4. Results

Test results are summarized in Tables 3–5. In general, the "resistance" testing was satisfactory, but there were minor problems with flexibility. Photographs of some of the test panels are included in the Appendix.

Table 3. Results for white no. 17925.

Test	Substrate		
	Pretreated Steel	**Bare Aluminum**	**Pretreated Aluminum**
Color no. 17925	Pass[a]	—	—
Gloss (60°/85°)	97.5 / 96.4[b]	—	—
Flexibility	Pass	Pass	Pass
Crosshatch adhesion	Pass (5B)	Pass (4B)	Pass (5B)
Acid resistance	Pass	Pass	Pass
Water resistance	Pass	Pass	Pass
Hydrocarbon resistance	Pass	Pass	Pass
Lube oil resistance	Pass	Pass	Pass
Hydraulic fluid resistance	Pass	Pass	Pass
DS2 resistance	Pass	Pass	Pass
Chemical agent resistance	Pass	—	—
Intercoat dry adhesion (53039)	—	Pass (5B)	—
Intercoat dry adhesion (64159)	—	Pass (4B)	—
Intercoat wet adhesion (53039)	—	Pass	—
Intercoat wet adhesion (64159)	—	Pass	—
Salt fog—scored	Pass	Pass	Pass
Salt fog—unscored	Pass	Pass	Pass

[a]Customer decision on acceptability; however, good visual match, and instrumentally determined as ΔE_{NBS} ~0.5 units when compared to the FED-STD-595, color no. 17925 chip.
[b]Customer decision on acceptability.

Table 4. Results for green no. 24533.

Test	Substrate		
	Pretreated Steel	Bare Aluminum	Pretreated Aluminum
Color no. 24533	Pass[a]	—	—
Gloss (60°/85°)	21.6/49.6[b]	—	—
Flexibility	Pass[c]	Pass	Pass
Crosshatch adhesion	Pass (5B)	Pass (5B)	Pass (5B)
Acid resistance	Pass	Pass	Pass
Water resistance	Pass	Pass	Pass
Hydrocarbon resistance	Pass	Pass	Pass
Lube oil resistance	Pass	Pass	Pass
Hydraulic fluid resistance	Pass	Pass	Pass
DS2 resistance	Pass	Pass	Pass
Chemical agent resistance	Pass	—	—
Intercoat dry adhesion (53039)	—	Pass (5B)	—
Intercoat dry adhesion (64159)	—	Pass (4B)	—
Intercoat wet adhesion (53039)	—	Pass	—
Intercoat wet adhesion (64159)	—	Pass	—
Salt fog—scored	Pass	Pass	Pass
Salt fog—unscored	Pass	Pass	Pass

[a]Customer decision on acceptability; however, good visual match, and instrumentally determined as ΔE_{NBS} ~1.75 units when compared to the FED-STD-595, color no. 24533 chip.
[b]Customer decision on acceptability.
[c]Some delamination at small radius bend (see section 5; Figure A-3).

Table 5. Results for black no. 17038.

Test	Substrate		
	Pretreated Steel	Bare Aluminum	Pretreated Aluminum
Color no. 17038	Pass[a]	—	—
Gloss (60°/85°)	97.3/96.2[b]	—	—
Flexibility	Pass	Pass	Pass
Crosshatch adhesion	Pass (5B)	Pass (4B)	Pass (5B)
Acid resistance	Pass	Pass	Pass
Water resistance	Pass	Pass	Pass
Hydrocarbon resistance	Pass	Pass	Pass
Lube oil resistance	Pass	Pass	Pass
Hydraulic fluid resistance	Pass	Pass	Pass
DS2 resistance	Pass	Pass	Pass
Chemical agent resistance	Pass	—	—
Intercoat dry adhesion (53039)	—	Pass (5B)	—
Intercoat dry adhesion (64159)	—	Pass (4B)	—
Intercoat wet adhesion (53039)	—	Pass	—
Intercoat wet adhesion (64159)	—	Pass	—
Salt fog—scored	Pass	Pass	Pass
Salt fog—unscored	Pass	Pass	Pass

[a]Customer decision on acceptability; however, good visual match, and instrumentally determined as ΔE_{NBS} ~1.79 units when compared to the FED-STD-595, color no. 17038 chip.
[b]Customer decision on acceptability.

5. Discussion

The ultimate criterion for a CARC substitute is its chemical agent resistance, and the results from the U.S. Army Edgewood Chemical and Biological Center for all three powder coatings were excellent with readings of less than 10-μg HD (mustard agent) on each test panel. The test for GD (nerve agent) is under revision and was not run. All three also showed acceptable resistance to DS2 exposure, with minimal color changes and no softening, indicating that decontamination of surfaces exposed to chemical warfare agents would not adversely affect the materials. Adhesion of each powder coating to the three substrates was excellent. The purpose of the topcoating (intercoat adhesion) test, with the subsequent crosshatch and wet tape adhesion tests, was to validate the ability to topcoat the powder used as a primer or to repair or rework powder coated items later. Even at the high gloss levels obtained for the white and black submissions, the results were excellent. Resistance to exposure to water, acid, hydrocarbon fluid, hydraulic fluid, and lubricating oil was excellent, typical of a quality epoxy coating. All three of the powder coatings performed very well in the corrosion resistance (salt fog) test. The aluminum substrate had little score corrosion and only a few defects elsewhere after 1008-hr exposure. The steel exhibited some score corrosion, but with minimal undercutting, and also had few defects elsewhere.

As previously indicated, the thickness of the test panels precluded using the mandrel flexibility test method specified in MIL-P-53022 and normally used in powder coating EPP testing. Instead, the conical mandrel flexibility test (ASTM D 522, Method A) was used. The only defect noted was for the sea foam green color on the pretreated steel substrate. There, delamination was noted for a diameter up to ~1/2 in. The test was performed on three different panels with dry film thicknesses of ~1.53, 2.25, and 3.09 mil. Since the flexibility was acceptable for the other two substrates, the problem likely lies with the surface preparation and not with the powder coating. However, this would indicate that the pretreatment process and the dry film thickness must be closely monitored until satisfactory flexibility is obtained. Visual appearance and instrumental determination of color difference between the samples and the FED-STD-595 samples were acceptable, but color acceptability is usually a customer decision. Also, as previously indicated, while all three colors performed well in the corrosion resistance test and would therefore perform acceptably as primers, when a CARC topcoat is applied, the infrared reflectance of the system could be affected and the camouflage properties compromised by the black or sea foam green colors, and solar heat loading could be increased.

6. Conclusions

The only problem noted in this study was the delamination noted during the flexibility test for the sea foam green color on the pretreated steel substrate. Since this is likely a pretreatment problem rather than a problem with the powder coating, ARL believes that all three Sherwin-Williams products tested in this project are acceptable for use as substitutes in the CARC system. It is, of course, the user's responsibility to monitor the surface preparation, application, and curing processes to ensure satisfactory results in a production environment. The three powder coatings are Sherwin-Williams product EWS8-9004 white no. 17925, EGS2-9007 sea foam green no. 24533, and EBS8-9003 black no. 17038.

7. References

1. MIL-P-53022. *Primer, Epoxy Coating, Corrosion Inhibiting, Lead and Chromate Free* **1988**.

2. MIL-PRF-22750. *Coating, Epoxy, High-Solids* **1994**.

3. MIL-P-53084. *Primer, Cathodic Electrodeposition, Chemical Agent Resistant* **1994**.

4. MIL-C-53039. *Coating, Aliphatic Polyurethane, Single Component, Chemical Agent Resistant* **1993**.

5. MIL-DTL-64159. *Coating, Water Dispersible Aliphatic Polyurethane, Chemical Agent Resistant* **2002**.

6. ASTM D 3359. Standard Test Methods for Measuring Adhesion by Tape Test. *Annu. Book ASTM Stand.* **2002**.

7. FED-STD-141. *Paint, Varnish, Lacquer, and Related Materials: Methods of Inspection, Sampling, and Testing* **2001**.

8. ASTM D 522. Standard Test Methods for Mandrel Bend Test of Attached Organic Coatings. *Annu. Book ASTM Stand.* **2001**.

9. MIL-C-46168. *Coating, Aliphatic Polyurethane, Chemical Agent Resistant* **1993**.

10. FED-STD-595. *Colors Used in Government Procurement* **1994**.

11. ASTM D 523. Standard Test Method for Specular Gloss. *Annu. Book ASTM Stand.* **1999**.

12. ASTM B 117. Standard Practice for Operating Salt Spray (Fog) Apparatus. *Annu. Book ASTM Stand.* **2002**.

Appendix. Photographs of Test Panels

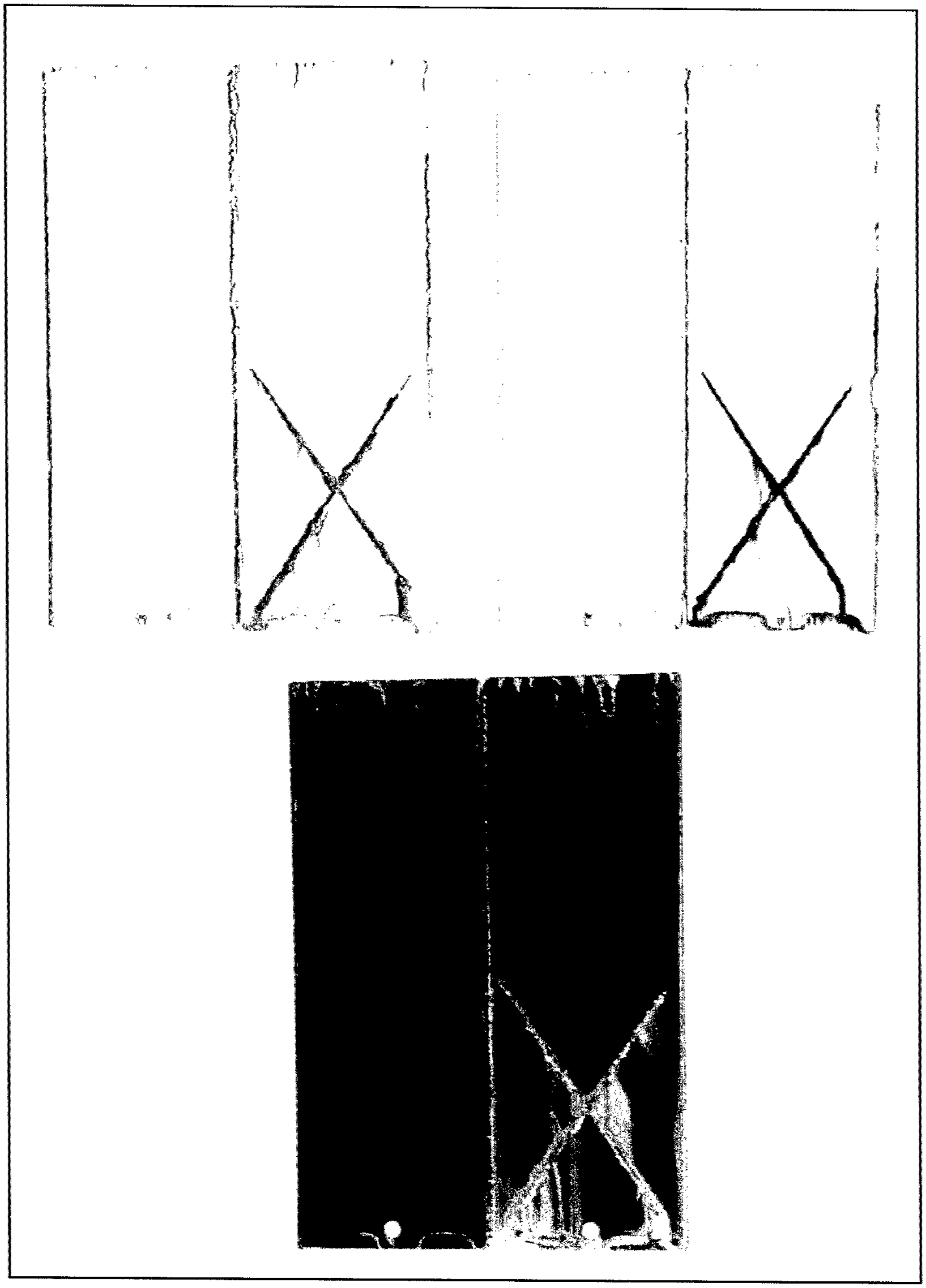

Figure A-1. Salt fog—steel substrate.

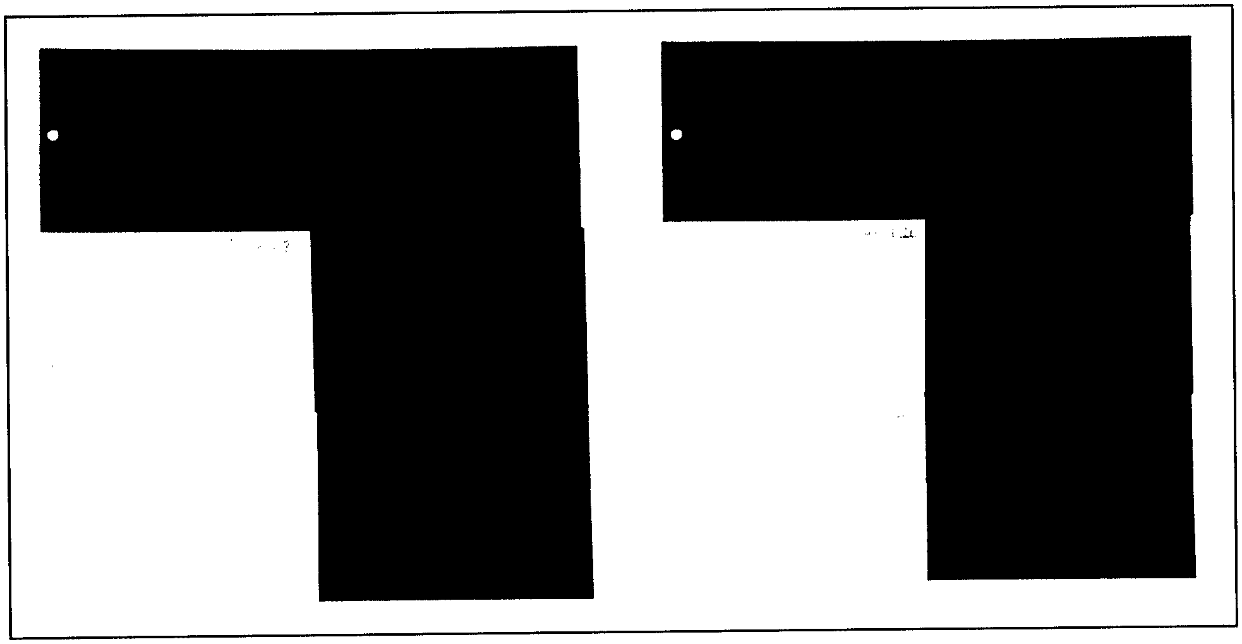

Figure A-2. Recoatability.

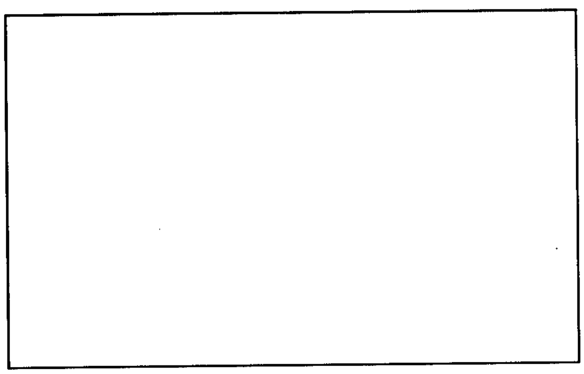

Figure A-3. Flexibility—green no. 24533 on steel.

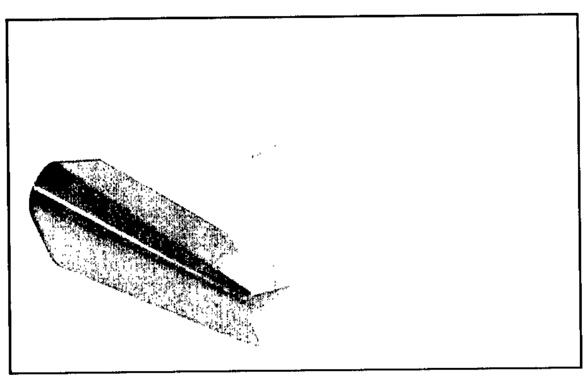

Figure A-4. Flexibility—all coatings on aluminum.